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SONIC innovations

Expansion as a Sound Processing Tool in Hearing Aids

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Abstract

Compression is a reduction of gain applied to a signal as it increases in intensity above a threshold or kneepoint. The inverse of compression, termed expansion, increases applied gain as the signal intensity increases. Expansion is widely used as a noise reduction tool in telecommunications and professional audio. This paper will explain expansion and its potential for hearing aid applications and give an example of its current use in a digital signal processing hearing aid.

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Audio Expansion?

A linear I/O function is defined as having a slope of 1. A slope less than 1 defines a compres-sion function while a slope greater than 1 defines an expansion function (Figure 1).

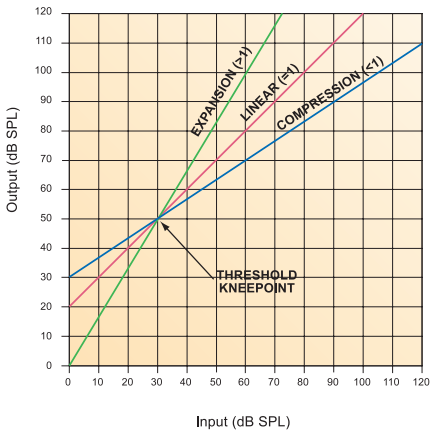

Figure 1. I/O Functions. 30 dB Kneepoint, 20 dB Gain.

Expansion applies increasing gain to a signal as it increases above a predetermined intensity (a threshold or kneepoint). Below the threshold or kneepoint, gain is reduced as signal intensity decreases.

Historical precedent for expansion as a noise reduction method can be found in professional audio and telecommunications where a technique called companding (from compressing + expanding) is used in both industries. Compressing the signal prior to transmission or recording allows a "hotter" signal to be used. At the output, downward expansion restores the original dynamics of the softer levels of the compressed signal and reduces the absolute and relative levels of noise resulting from recording or transmission.

Noise-gating (a.k.a. squelch in RF communications) is another use of expansion in professional audio and is similar to how expansion is currently used in hearing aids. Each of several microphones in an ensemble recording is dedicated to a single instrument. Expanders are used on each of these microphones as noise gates. The expansion threshold of each gate is set such that the direct sound of the instrument can "open" the gate, but ambient noise (rustling sheet music, shuffling feet, etc.) and sound spilling over from adjacent instruments cannot open the gate. Very steep expansion ratios are used in this application.

Audion Expansion in Hearing Aids

Wide dynamic range compression (WDRC) hearing aids typically apply ever-increasing gain as signals become softer. The result is noisy amplification, especially in relatively "quiet" environments. Compression amplifiers with linear gain below the kneepoint still apply maximum gain to the softest sounds. One of the earliest suggestions that expansion could be used to reduce this annoyance in hearing aids was made by Villchur[1]. This idea was revisited several times[2, 3, 4] with limited success. Reviewing this prior work reveals that high expansion kneepoints and/or steep functions can make speech intelligibility worse by reducing the gain for soft consonant cues. In addition, a steep expansion function can cause audible artifacts in signals at the level of the kneepoint.

Expansion also has been used above a primary kneepoint with an aim toward increasing consonant-to-vowel ratios[5]. The expectation was that gain for soft, high-frequency consonants could be expanded to a level above the vowel intensity. These experiments did not produce anticipated results. The work[5] suggested that the expander circuit may have been responding to vowel energy in addition to consonant energy, causing masking. But it may well have been that kneepoints were too high for soft consonants to reach into the expansion region.

Natura™ Expansion

Some current digital hearing aids use a simplistic expansion feature to quiet noisy microphones. These circuits do nothing, however, to attenuate the low-intensity environmental sounds which receive the most gain from WDRC amplification.

A new digital hearing aid family, the **SONIC innovations** NATURA, uses expansion with variable kneepoints and slopes operating in nine independent channels[6]. The expansion parameters are set to mirror the long-term average speech spectrum. This shaping results in a "sweet spot" for speech sounds (Figure 2) with the most gain being applied at the

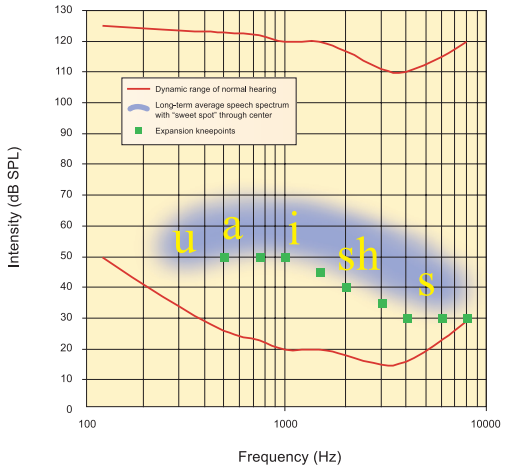

Figure 2. Speech Spectrum and "Sweet Spot"

kneepoints in each channel. Above the kneepoints, each channel is operating as a compression amplifier. Environmental sounds with intensities below the kneepoints fall in the expansion region of each channel and receive less gain. This is not to say that these sounds are attenuated. Rather, they are still amplified, but applied gain continues to be reduced as the sounds get softer.

The expansion ratios and kneepoints vary by frequency across NATURA's nine channels and can be set for different types of hearing loss by selecting one of four expansion options available in the **SONIC innovations** EXPRESS*fit*™ fitting system (Figure 3). Expansion setting #3, for example, provides slightly

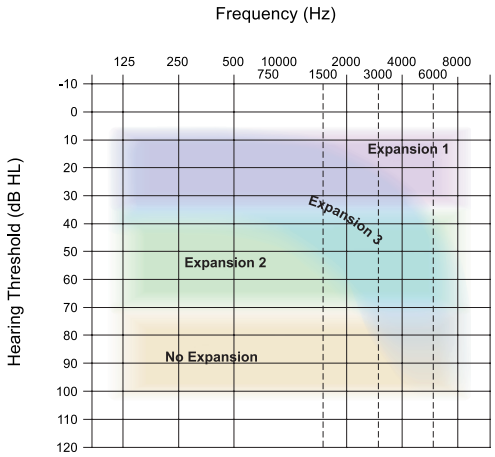

Figure 3. Expansion Settings by Range of Hearing Loss

higher kneepoints and expansion ratios for low frequencies where there is normal low-frequency hearing; low kneepoints and mild expansion ratios are programmed in the critical high-frequencies. Occasionally, the gain required for an individual may need some adjustment relative to the prescribed fitting. Once the gain is adjusted to meet the patient's particular needs, an expansion option more appropriate to the patient's requirements may be selected as well.

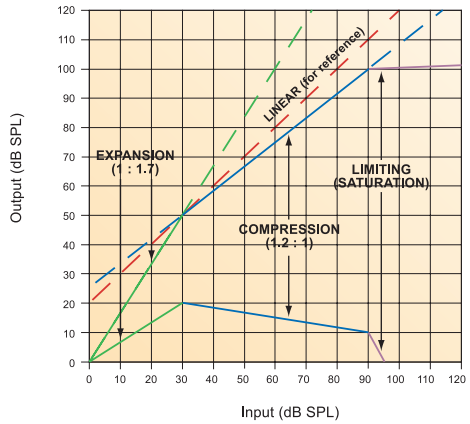

Figure 4. NATURA Input vs. Gain and Output Functions

The input/output and input/gain characteristics of each of NATURA's nine channels, although set independently, take on the general relationships shown in Figure 4. The dashed lines for the linear, compression, and expansion functions are for reference.

Patient Benefit

It is important to understand that expansion is not a tool for high-noise environments. Its purpose is to de-emphasize soft background sounds and keep "quiet" environments "quiet." Such sounds would otherwise receive too much gain from a WDRC amplifier and become annoying, fatiguing, or possibly a hindrance to speech understanding.

By definition of its application in hearing aids, expansion is expected to result in less functional gain than WDRC at some frequencies. This is a desired feature when considering the goal of reducing gain for sounds below the average intensity of speech. But because the intensity of speech sounds varies by frequency, the successful application of expansion is only effective if realized in NATURA's multiple, narrow bands. The functional gain trade-off for a quieter environment is well tolerated. One reason is that the energy most affected by this expansion system is in the low frequencies. Low frequencies are more efficient maskers, but do not carry as much speech intelligibility information as high frequencies. Therefore, higher expansion kneepoints are used in lower frequencies where environmental noise energy is greatest. This is especially true when a patient has normal or near-normal hearing below about 1500 Hz. Figure 5 demonstrates the

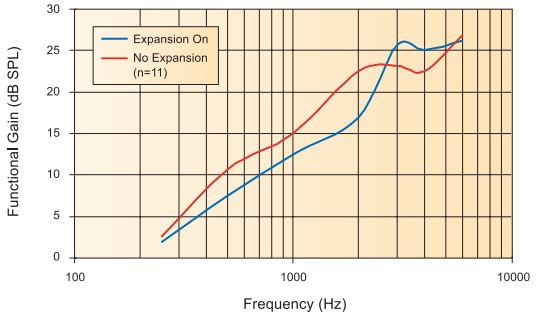

Figure 5. Functional Gain with and without Expansion

reduced functional gain in lower frequencies with expansion selected versus the same fittings with no expansion (3.5 dB, on average). The expansion option for each subject in the sample was selected according to Figure 5. In the "No Expansion" option, the gain functions are linear below a 40 dB SPL kneepoint. Patients report more listening comfort and less fatigue from amplified background sounds with appropriate expansion selected.

Summary

Audio expansion has been used as a noise reduction method in telecommunications and professional audio for many decades. It was proposed as a method for avoiding overamplification of low-level environmental noise in WDRC hearing aids as early as 1973. We have demonstrated how expansion has now been successfully applied for this purpose in a proprietary, nine-channel, DSP hearing aid.

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Editor's Note: For further information, please see the companion paper "Uses of Expansion to Promote Listening Comfort with Hearing Aids" by Ghent, Nilsson, and Bray (2000).

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